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A Narrative Summary and Independent Assessment of the Active Denial System

The Human Effects Advisory Panel

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Executive Summary

In July 2007, an assessment of research was conducted on the Active Denial System's effectiveness and safety risks by an independent advisory body called the Human Effects Advisory Panel (HEAP), which has served as an independent review body since 1998. The Joint Non-lethal Weapons Directorate funded this assessment with the intention of ensuring that the research and research findings were thorough, accurate, and comprehensive.

This assessment specifically includes:

- A summary of effectiveness and safety research of 94-95 GHz millimeter wave energy completed prior to 2002. (Section 1)
- An assessment of the Air Force Research Laboratory's ADS effectiveness and safety research since 2002. (Section 2)
- An assessment of effectiveness and safety research supporting the development and fielding of the Active Denial System. (Section 3)

The HEAP's Assessment of Completed ADS Research

The HEAP found the conduct of the Air Force Research Laboratory's (AFRL's) overall bioffects research to be thorough and accurate. The AFRL's research provided a comprehensive understanding of 94-95 GHz millimeter wave energy. The HEAP reviewed the research and agreed with the findings of AFRL's research as follows:

The HEAP found the conduct of AFRL's overall bioeffects research to be thorough and accurate.

- The safety margin between the repel response and thermal injuries to eyes has been determined.
- The safety margin between the repel response and thermal injury to skin has been determined.
- The wearing of contact lenses during an ADS exposure does not pose a greater risk than not wearing contact lenses.
- LASIK surgery had no significant effect on ADS interaction with the eyes.

- An ADS exposure does not cause unusual heating of the surface around the eye or face due to the eyewear and there is no indication that night vision devices or binoculars focus the beam toward the area of the eye.
- Repetitive, low-level ADS 94 GHz exposures (as would be experienced by operators) did not cause degradation of visual functions and did not decrease contrast sensitivity.
- Normal skin applications, such as cosmetics, have little effect on ADS's interaction with skin.
- There are no age-related differences in response to ADS exposures.
- Promotion or co-promotion of cancer due to ADS exposure is very unlikely.
- An ADS exposure had no effect on the male reproduction system.
- An ADS exposure had no deleterious effect on birth defects.
- Alcohol consumption had little effect on the repel response to ADS exposure.

The HEAP's Assessment of Completed ADS Field Demonstrations

The AFRL conducted ADS bioeffects research in field settings, producing findings that could not be obtained in a laboratory setting. Again, the HEAP found the research thorough and rigorous. The HEAP assessment noted that during full body, human exposures in field environments, the following research had been completed:

- The ADS beam had been defined and characterized over its intended range.
- The ADS reflections or multipath effects had been assessed.
- The ADS safety margin for humans in field demonstrations was determined.

- The ADS effectiveness and infrequent small injuries[1] (pea-sized blisters) were reported in field demonstrations.

During a demonstration at Moody Air Force Base, one volunteer airman experienced second degree burns (blister injuries) on his legs from an ADS overexposure. These blister injuries were much more significant[2] than previously observed. The safety investigation concluded that incorrect power and duration settings were used for the range at which ADS was operating in the scenario when the injury occurred and thus contributed to the incident. The HEAP agreed with the findings of this safety investigation.

The HEAP's Conclusions

The HEAP concluded that ADS is a non-lethal weapon that has a high probability of effectiveness and a low probability of injury.

This millimeter wave energy's primary interaction is in the outer 1/64th of an inch of the skin and cornea, and its principal effect is thermal. The AFRL researchers have comprehensively examined these thermal effects in several climes and locales. They have also determined when this energy causes thermal injuries, and found a wide safety margin between the desired repel response and injuries. Additionally, they have assessed the many variables that could impact safety and effectiveness.

The HEAP continues to be impressed with the quality and thoroughness of AFRL's research. The AFRL's receptiveness to outside scrutiny, criticisms and recommendations is a reflection of its professionalism and conscientiousness. As one HEAP member stated, "Other research endeavors should be so thorough."

The HEAP has concluded that ADS is a non-lethal weapon that has a high probability of effectiveness with a low probability of injury.

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[1] These injuries were infrequent in that they occurred in less than one-tenth of one percent of the exposures.

[2] This injury was considered significant in that it was the only injury that required medical treatment.

Introduction

In July 2007, a third assessment of research was conducted on the Active Denial System's effectiveness and safety risks by an independent advisory body called the Human Effects Advisory Panel (HEAP). This panel completed two previous assessments, the first in 2002 and the second in 2004. The Joint Non-lethal Weapons Directorate requested all of the assessments. The intent of these assessments was to ensure the research and research findings were thorough, accurate and comprehensive.

The Joint Non-lethal Weapons Directorate also asked the HEAP to make its report of the third assessment suitable for public release, and a concerted effort has been made to make it understandable and explanatory. This assessment specifically includes:

- A summary of effectiveness and safety research of 94-95 GHz millimeter wave energy completed prior to 2002. (Section 1)
- An assessment of effectiveness and safety research since 2002. (Section 2)
- An assessment of effectiveness and safety research supporting the development and fielding of the Active Denial System. (Section 3)

The Human Effects Advisory Panel

The Human Effects Advisory Panel (HEAP), is an independent advisory body to the Joint Non-lethal Weapons Directorate, and conducted the assessments. This Panel provides advice on science and technology issues relating to non-lethal weapons, and any other issues the Directorate deems appropriate. The Panel is composed of recognized experts, with no vested interests in the issue being assessed. They are selected based on having the expertise necessary to competently assess the quality of the research.

For this third independent assessment, a concerted effort was made to have the same Panel members who completed the two earlier assessments of ADS. These Panel members are recognized experts in directed energy, their bioeffects and non-lethal weapons. These Panel members were:

Dr. Robert K. Adair: The Sterling Professor Emeritus of Physics, Senior Research Scientist, Department of Physics, Yale University (Participated in all three assessments)

Dr. Viktor E. Bovbjerg: Member of the Division of Biostatistics and Epidemiology, University of Virginia School of Medicine (Participated in all three assessments)

Dr. Donald N. Farrer: Previously Chief Scientist of Occupational and Environmental Health Directorate, Armstrong Laboratory, now a behavior toxicology consultant. (Participated in all thee assessments)

Dr. John M. Kenny: The Panel's principal investigator, senior research engineer at Penn State University's Applied Research Lab, and Associate Director for Institute for Non-Lethal Defense Technologies. (The principal investigator for all three assessments)

Dr. Lawrence E. Marks: Director, John B. Pierce Laboratory and Professor of Epidemiology and Psychology, Yale University (Participated in all three assessments)

Dr. Bosseau Murray, Professor of anesthesiology, Hershey Medical Center, Penn State University (Partially participated in the first assessment, and fully participated in the final two assessments)

Dr. Marvin Ziskin – Director, Center for Biomedical Physics, Temple University School of Medicine (Participated in all three assessments)

Early ADS Research

In the 1980's, researchers knew that radars at certain frequencies created a warming effect on personnel working near them. Scientist wondered if there was a possibility that millimeter wave energy could create a repel effect that might serve as a non-lethal weapon. Preliminary analysis indicated this repel effect was due to the stimulation of nerve endings in the surface layers of the skin. Researchers postulated a cause-and-effect relationship between this energy deposition and the repel response.

This hypothesis became the basis for preliminary research. Specifically, researchers sought to characterize this 94 GHz millimeter wave energy and the observed response. "The bioeffects at higher frequencies were unknown[3] to us," stated one AFRL researcher, "People didn't conduct research in this area. People conducted research at lower frequencies, relevant to cell phones."

In conducting research on animals, AFRL follows strict procedures as directed in Title 9, Code of Federal Regulations, "Animals and Animal Products," (Chapter 1, Subchapter A, "Animal Welfare," Parts 1, 2, and 3), DOD Directive 3216.1, "Use of Laboratory Animals in DoD Programs," April 17, 1995, and SECNAVINST 3900.38C. "The Care and Use of Laboratory Animals in DOD Programs," December 1, 2003. Their research protocols are reviewed and approved by an Institutional Animal Care and Use Committee (IACUC).

What is ADS?

The Active Denial System (ADS) is a directed energy system designed for use as a non-lethal weapon for the purpose of repelling personnel.

The system's effects are described in its concept of operations, developed by the US Joint Forces Command. "ADS uses a transmitter producing millimeter wave energy at a frequency of 95 GHz…." The concept of operations also states, "Traveling at the speed of light, the beam of energy reaches the targeted subject."

[3] These bioeffects were only unknown in that they were not known precisely and in detail. Extrapolations from other microwave research and theoretical considerations accurately predicted the bioeffects at this wavelength. These predictions were later confirmed with research.

The ADS creates a "… large spot size on target, covering potentially the whole body size." The energy "…penetrates approximately 1/64th of an inch into the skin, quickly heating up the skin's surface[4]. Within seconds, an individual feels an intense heating sensation that stops when the transmitter is shut off or when the individual moves out of the beam (i.e., is repelled)."

The ADS has evolved through three configurations. These are:

- The ADS, System 0: This is the first system. It is a fixed-site, field demonstrator, completed in December 2000 and located at Kirtland Air Force Base, New Mexico. It has a generator, which produces the millimeter wave energy. The energy is directed to an antenna, which projects the energy beam.
- The ADS, System 1: This configuration is mobile and was delivered in 2004. System 1 includes the same major components as System 0– a transmitter and antenna – but these components have been integrated into a hybrid electric High Mobility Multipurpose Wheeled Vehicle, or HMMWV. Only when the HMMWV is stopped is the ADS's millimeter wave energy employed, with the transmitter and antenna powered by both lithium batteries and the generator. A trained service member in the passenger seat inside the vehicle operates the system. He uses an image-intensified video camera and an infrared camera (for visualizing temperature elevation for darkness conditions) to acquire the target. The camera images are shown on a display/control panel in the operator station. Onboard and handheld laser rangefinders measure the distance to targeted personnel. The operator uses a joystick to move

[4] The ADS system is similar to a very bright searchlight with a wavelength of 0.3 millimeters instead of the 0.0005 millimeter wavelength of visible light. At the ADS wavelength, the energy penetrates clothes (unlike visible light), but is absorbed by the outer layer of skin (almost exactly like visible light). Even as very intense light on the skin, such as sunlight condensed by a lens stings, ADS energy stings. At the same intensity, the ADS wavelength energy feels the same as condensed sunlight but is less dangerous because the longer wavelength energy does not disrupt chemical bonds and is thus not carcinogenic as is the case for too strong sunlight.

the antenna and position it on a target. The operator then depresses the trigger, and the ADS energy hits the target. Additionally, the operator can apply varying energies on targets, for varying times. The operator may select four power levels, from 25 to 100 percent, and six different time settings[5].

- *The ADS, System 2:* This configuration is under construction. Its major components are basically the same as System 1. However, System 2 includes several improvements such as the ability to operate in higher environmental temperatures, a change in operating system software to provide even more levels of safety and salt/fog protection. System 2 also includes an enclosed, modular operating station, with protective armor. Because of the additional weight and cooling, System 2 is larger and heavier than System 1. System 2 can be transported on certain military vehicles such as the Heavy Expanded Mobility Tactical Truck (HEMTT).

The Need for ADS

ADS is a transformational program that allows non-lethal weapons to go beyond the range of rubber bullets.

Such a directed energy system is seen as having several advantages over kinetic energy, non-lethal weapons like rubber bullets. Today's kinetic energy, non-lethal munitions have a maximum range of about 75 meters. However, the "extended range is the most dramatic enhancement Active Denial Technology provides the warfighter," states the concept of operations. It goes "…beyond effective small arms."

ADS is a transformational program that allows non-lethal weapons to go beyond the range of rubber bullets.

This directed energy system is more accurate than kinetic energy, non-lethal munitions[6]. No windage or elevation corrections are required for fire solutions; what is targeted is hit. And while kinetic energy, non-lethal munitions have sometimes caused serious and

[5] The six time settings are 1, 2, 3, 4, 5, and 6 seconds.

[6] To again use the searchlight comparison, ADS is more accurate because the beam is not subject to inaccuracies caused by windage and elevation.

irreversible effects, this directed energy is seen as assuring consistent, universal, and reversible effects.

How ADS might be used

The concept of operations for the Active Denial System envisions it being used in six types of scenarios:

- Defense of a perimeter
- Crowd control
- Protection of military forces
- Enhancing maneuver, particularly in an urban environment
- Protection of a harbor/channel
- Protection of a pier

Access to Some ADS Information is Restricted

Certain information about the Active Denial System is considered to be sensitive and access to this information has been restricted by law. Understandably, certain specific details regarding ADS's performance parameters cannot be mentioned in this report. This restricted information includes.

- Operational range
- Size of the beam, or "spot size" at any range
- Measured antenna gain
- Power density on target or at any range
- Specific time it takes to achieve an effect
- Unconventional countermeasures

This information has been classified per the direction of:

- Presidential Executive Order 12958, "Classified National Security Information," April 20, 1995
- Department of Defense security guidance regarding High Power Microwave Technology, dated June 21, 1999

- Derivative Department of Defense guidance regarding Active Denial Technology, dated December 8, 2000 that includes an addendum to that guidance dated November 2005

Within these restrictions, however, it is the intent of this report to be as complete and transparent as possible.

Exposures Made with 94 and 95 GHz Millimeter Wave Energy

Some of the earlier ADS research was done with exposures made at 94 GHz millimeter wave energy, while some was done at 95 GHz. The frequency of System 1 and System 2 is 95 GHz millimeter wave energy. The question often arises is, 'what is the difference between these two frequencies?'

Panel member and noted expert on millimeter wave energy, Dr. Marvin Ziskin commented: "Going from 94 to 95 GHz has essentially inconsequential differences. There is a trivial difference in penetration depth, but that difference is so small that that is beneath the level of detection, and there is no biological effect that would be different at these levels."[7]

[7] Dr Marvin Ziskin comments at the HEAP meeting, 10 July 2007

Section 1: The HEAP's Assessment of the ADS Laboratory Research

The HEAP's First and Second Assessments of ADS Bioeffects Research: 2001–2004

In 2001, the JNLWD asked the HEAP to conduct an independent assessment of the effectiveness and safety risks of the ADS. The Panel met in June 2001 and again in February 2002.

As a result of this first assessment, AFRL developed and implemented their Bioeffects Research Plan Supporting Deployment of the Active Denial System. This plan was a roadmap for the ADS bioeffects research, which would lead to the ability to test ADS in a field environment. The plan addressed the anticipated needs of warfighters as well as policy makers and the public's concerns.

In 2004, the HEAP conducted its second independent assessment of the ADS research. By that time, AFRL had completed the bulk of the research needed to understand the safety risks and the effectiveness of ADS.

ADS Exposures to the Eye

AFRL researchers concluded and the HEAP panel concurred that the probability of eye damage caused by ADS exposure is very low. The innate blink reflex causes the eyelid to close upon sensing of the millimeter wave energy, protecting the eye from damage.

The HEAP panel concurred that the probability of eye damage caused by ADS exposure is very low.

Various eye exposure tests showed that a safety margin exists between eye detection/aversion, and temporary as well as irreversible damage. This safety margin is graphically depicted by plotting data from the various eye tests to include: eye detection in non-human primates; eye aversion in humans and non-human primates; temporary eye damage in non-human primates; and permanent damage in rabbit corneas. The safety margin is depicted below. As can be seen, no overlap occurs between these responses.

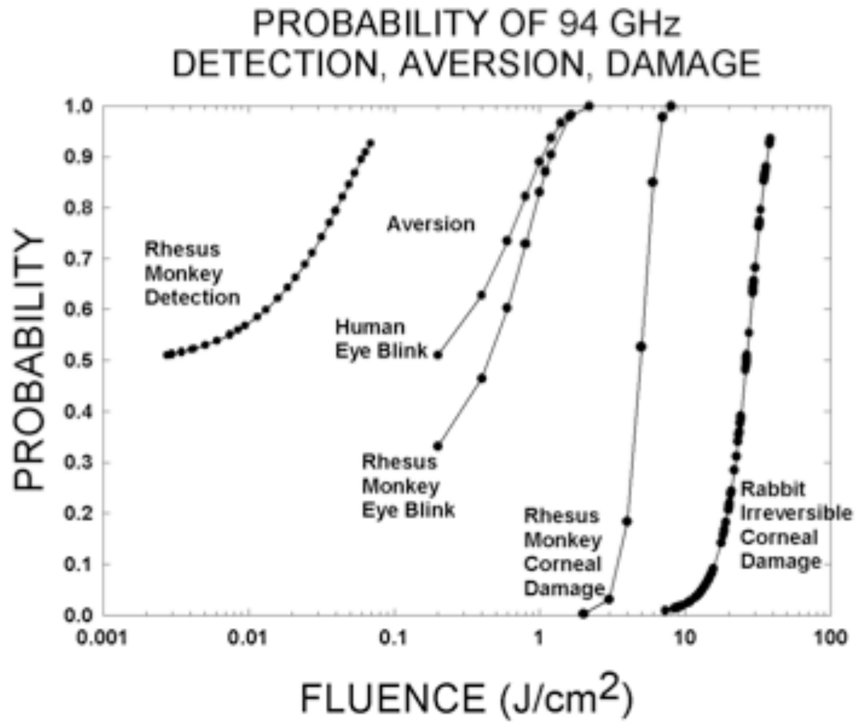

Figure 1. Summary graph of probability for detection, aversion as eye blink, temporary and permanent corneal damage[8]

Additional eye research concluded that:

- The wearing of contact lenses during ADS exposure does not pose a greater risk than not wearing contacts."
- LASIK surgery has no significant affect on ADS interaction with eyes except in long and powerful exposures[9]

[8] Fluence is a measure of energy density. To read this graph, the reader can assume that the energy was deposited in less than 200 milliseconds.
[9] In the six-second exposures, ophthalmologists determined that irreversible damage occurred to LASIK eyes at energy levels of 26.5 Joules square centimeter, while irreversible damage to non-LASIK eyes occurred at 31 Joules per square centimeter. The conclusion reached by researchers is that this difference does not become an issue because six-second exposures to the cornea are unlikely.

- Eyewear, such as eyeglasses, binoculars and night vision goggles, do not affect the ADS's interaction with the eyes.
- The eyes would have to be held open to achieve damage.
- Repetitive exposures do not cause degradation of visual functions and do not decrease contrast sensitivity.

ADS Exposures to the Skin

AFRL researchers concluded, and the HEAP panel concurred, that the probability of skin damage caused by the ADS exposure is very low. Research found that the ADS's power density and durations did cause the desired repel response, but did not cause first, second or third-degree burns.

The HEAP panel concurred that the probability of skin damage caused by ADS exposure is very low.

AFRL research found that:

- There is a significant margin between the ADS's power density levels and durations required to produce the repel effect and the power density levels and durations that caused second-degree burns.
- The ADS's repel effect in humans occurs at slightly higher than 43-44 °C. First-degree burns occur at about 51°C, and second-degree burns occur at about 58°C.
- Normal skin applications, such as cosmetics, have little affect on ADS's interaction with skin.
- There are no age related differences in responses to ADS exposures.
- Exposure to ADS to has no deleterious effects on the male reproductive system.
- Exposure to ADS is unlikely to initiate cancer. [10]
- Exposure to ADS has no deleterious effect on fetal development.
- Alcohol consumption had little effect on the repel response to ADS exposure.

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[10] Mason *et al*. "Lack of effect of 94-GHz exposure in an animal model of skin carcinogenesis," *Carcinogenesis,* Vol 22 no.10 pp 1701-1708, 2001

Conclusion

AFRL's research had addressed scientifically plausible issues related to ADS's use as a non-lethal technique, and had determined those conditions for the safe and effective use of ADS. At the end of these two assessments, the HEAP concluded that the ADS had a high probability of effectiveness and a low probability of injury. The HEAP urged the AFRL researchers to test the ADS in field environments.

Section 2: The HEAP Assessment of ADS Field Demonstrations

The HEAP's Assessment of Research Supporting Development and Fielding

In conducting its third assessment in July 2007, the HEAP found the conduct of the ADS bioffects research to be thorough and accurate. AFRLs' research had provided a comprehensive understanding of 94-95 GHz millimeter wave energy. This research does much to answer the question 'is this energy safe as well as effective?' The answer is, 'yes, under certain conditions.' AFRL's research has determined appropriate conditions for its use.

AFRL conducted research to determine the ADS bioeffects in anticipated field settings. This effort produced findings that could not be obtained in a laboratory. Together, the field and laboratory bioeffects research guided the development of the Active Denial Systems 1 and 2. The HEAP found the research to be thorough and accurate and believes that it contributed to reducing the safety risks and increasing the effectiveness of ADS.

The Panel reviewed an April 2007 incident in which an airman received second-degree burns on the legs as a result of an exposure to the Active Denial System and provides comment.

ADS Beam Characterization

The ADS beam is not uniformly projected over the ranges being considered as noted in the Panel's 2002 report. The beam changes as the range changes, and so does the power level. Defining the beam at given ranges was key to effectiveness and safety.

The AFRL researchers defined the beam over its intended ranges using carbon-loaded Teflon panels. These panels are coated with carbon powder, which absorbs ADS energy. By projecting the beam on the panels at given ranges, the power density can be measured. At the same time, infrared cameras can measure the temperature increase at these given ranges, so power levels can be related to temperature increases. The result of these tests was a model that AFRL could use to predict power densities on targets. The size of these carbon-loaded Teflon panels also allowed a large cross section of the beam to be measured, so that high and low power densities within the beam could be identified.

Researchers determined where the beam was most intense. This determination is a critical safety issue. Researchers also used the carbon-loaded Teflon panels and infrared cameras to map the field at the various scenario locations prior to field tests. This understanding of the beams power levels at given ranges allows the operator to adjust the system's power, which better ensures ADS safety and effectiveness.

Reduced Power Density at Fresnel Maximum and Antenna Focusing

Researchers had to ensure that the beam's power at the Fresnel maximum[11] was not so intense that it caused serious thermal injuries. In early 2001 testing, AFRL measurements found that System 0's power density at the Fresnel maximum was too high, and researchers reduced the power at the Fresnel maximum by correcting the focus of the antenna. This adjustment led to changes in the hardware design for System 1. As a byproduct of this research effort, AFRL improved the method for adjusting the ADS antenna.

Reflections or Multipath Effects Assessed

"There is a possibility that reflections off some objects could increase millimeter wave energy and thus cause greater exposures," stated Panel member Dr. Marvin Ziskin in the first independent assessment in 2002. These reflections are called multi-

[11] There is a range at which the power density is at its peak. In a free field ideal radiating environment, the first peak of the power intensity on boresight as the range is decreased from the near field boundary is called the Fresnel maximum.

path effects because they have more than one path to the target. These multipaths can theoretically represent heating 2-4 times higher than that produced by an unreflected beam of the same power density.

Researchers needed to determine if these reflections increased the risks of thermal injury and had an adverse impact on effectiveness. Using the carbon loaded Teflon panels, they quantified the multipath effects in 2003. Researchers first projected millimeter wave energies at a carbon loaded Teflon target, and measured the power density. They then reflected the same amounts of energies off the ground. Researchers compared the direct shots with the reflected shots, and discovered that the power densities of the reflected shots were larger.

Researchers exposed volunteers to a constant power level with and without reflecting the beam off of the ground. The results indicated that personnel responded quicker to beams reflected off the ground. Analysis of the infrared heating data showed that beams bounced off the ground produced a 10.9 °C increase in peak skin temperature as compared to a 7.4 °C increase in peak skin temperature when the beam was aimed directly at the backs of personnel.

Prior to field tests, researchers mapped the field with carbon-loaded Teflon panels and predicted power densities resulting from possible multipath exposures. These panels were used to characterize the reflective nature of a variety of surfaces – terrain, poles, chain link fence, roads, and sides of buildings. In a recent maritime scenario, researchers analyzed beam reflections off boats, which resulted in the ability to use lower power levels while achieving the same effectiveness. Researchers concluded that increased temperature from the reflected exposures resulted in faster repel responses, and faster repel responses compensated for higher power density, which resulted in no real reduction in the safety margin. Considerations or reflections have also been incorporated into tactics, techniques and procedures for the Active Denial System.

Preparing for Full Body, Human Exposures in Field

Initial human exposures were made on the backs of the body rather than on the front because all of the eye safety studies had not been completed. These initial exposures were made on volunteers in a carefully controlled process that had been approved by an Institutional Review Board. Researchers also wanted to determine if there was any repel time differences between back and frontal exposures that might affect safe margins.

As the eye safety research was completed, AFRL researchers progressed to frontal exposures using an incremental and conservative approach. All volunteers were medically examined prior to exposures, with particular emphasis on visual exams. Frontal exposures began with volunteers partially clothed in order to gather data on skin temperatures. The initial frontal exposures involved relatively low power densities, which were known to the volunteers. The power densities were gradually increased until the lowest effective power density was determined. Before and after each individual was exposed, shots were made on carbon Teflon panels to predict the temperature and power density on the target.

As more frontal exposures were conducted, participants were allowed to be fully clothed and they eventually received power densities unknown to them. These experiments determined skin temperatures and aversion behaviors in frontal exposures, and this data was used to develop the parameters for the limited military assessment, conducted at Kirtland Air Force Base, September 16-26, 2003.

The Limited Military Utility Assessment, Kirtland Air Force Base, September 2003

A medical monitor was used for all human research protocols. This monitor ensured strict adherence to the human-use protocol. For the September 2003 Limited Military Utility Assessment, multiple military organizations and government agencies sent 35 volunteers to the assessment. These volunteers were medically screened to avoid medical conditions that might confound results or pose an unknown safety risk. For example, personnel with metal implants and skin conditions were disqualified as were personnel wearing contacts and glasses. The eyewear research described in Section 2 had not been completed when this assessment was conducted. Upon arrival at the test site, participants were screened again. Prior to and after exposures, they were screened and their physical condition documented.

During this assessment, 636 directed energy shots were fired at the volunteers in field scenarios. The medical monitor reported, “All reactions/injury were minor.” Also, they resulted in “rapid recovery, no sequela[12].” Five personnel had symptoms lasting more than 24 hours. These symptoms were characterized as pain, redness around the orbit of the eye, as well as conjunctivitis and one case of microblisters on the eyelid. Fifteen personnel had more subjective symptoms lasting over 15 minutes and less than two to three hours. These symptoms were described as pain, tenderness, tingling, and warmth. All responses were consistent with those expected in the human use protocol.

The ADS Safety Margin

The ADS safety margin between the repel effect and thermal injuries had been measured by research on stationary animals and humans in the lab. However, AFRL researchers discovered a wider safety margin for humans in the field than in the laboratory environment. Human volunteers in the field experienced larger beam, or spot sizes, than those in the lab setting. As a result of these factors, human volunteers moved out of the beam at much lower power densities/durations and temperatures than those in the lab. As one Air Force Research Laboratory’s researcher wrote: “ … the skin temperature required to produce the required repel effect was approximately 10 °C higher in laboratory psychophysics studies than in whole body field exposure experiments. This indi-

[12] Sequela is a medical term that describes a condition that is a consequence of an injury.

cates that the safety margins derived from static targets in the laboratory are conservative."

Environment Has No Impact on ADS Energy on the Skin

In field tests, volunteers reported that sweat-soaked shirts intensified the feeling of ADS exposures. To investigate this phenomenon, researchers conducted two sets of experiments.

One experiment exposed personnel under different combinations of ambient temperatures and humidity, with temperatures of 28 to 34 °C, and humidity at 30 and 80 percent. For each temperature and humidity combination, subjects received 32 exposures of varying intensity, each lasting three seconds. Personnel were asked to report any sensation of pain. Researchers focused on intensities, which personnel reported as painful at least 33 percent of the time. The researchers also assessed pain thresholds against skin temperatures. They found that the participants reported the same pain thresholds for all temperature and humidity combinations. These environmental conditions did not impact pain thresholds.

The second set of experiments exposed personnel wearing a dry T-shirt and wet T-shirt in a temperature of 28 °C and humidity of 50 percent. Personnel experienced the same varying intensities as in the first set of experiments, again reporting any painful sensations. Researchers found personnel wearing wet T-shirts had some increased tolerance over personnel wearing dry T-shirts.

The HEAP pointed out that the statement 'the environment has no impact' is misleading. Environments will reduce energy power levels, as pointed out by Panel members Dr. Adair and Dr. Ziskin. Dr. Diana Loree stated that the high humidity of such locations as Fort Benning, Georgia would reduce the power levels by about 10 percent as compared to a dry environment such as Albuquerque, New Mexico. Also, Dr Ziskin stated that rainfall occurring at a rate of one-inch per hour would attenuate power levels by about 25 percent. The HEAP stated that the conclusion should be restated to be "environment has no effect on energy on the skin."

Skin Heating Models

In the early research stages, researchers developed a skin-heating model to understand and predict the effects of millimeter wave energy. The model was limited because it was based on thermal data on static targets, and did not predict skin temperatures on moving targets.

Researchers have developed an improved model using more recent data from exposures. This model has accurately predicted when the individuals would be repelled. Researchers plan to further refine the model.

The HEAP commented that the model, while useful, has limited applicability. The skin's surface temperature is close to the temperature of outside air, with skin temperature becoming closer to core body temperature, the deeper it goes. The model is based on skin temperature measurements collected at Kirtland Air Force Base, which has an unusually warm and dry climate that is not reflective of all climates elsewhere. Thus, the model may not accurately predict skin temperatures and responses for personnel in humid and cold climates. Referring to the model, Panel member Dr. Bob Adair stated, "It has little generality. You have to be very careful using the model under different conditions."

Field Demonstration Results: Effectiveness and Minor Injuries

System 1 was demonstrated on volunteers in simulated operational scenarios in 2005 and 2006. During these demonstrations, over 3,500 exposures were made on more than 200 volunteers in three different environments. As part of the assessment process, 882 personnel associated with the demonstrations were asked to agree or disagree with statements about the Active Denial System's use. Of these, 99 percent agreed with the statement "ADS is an effective deterrent in crowd control situations." The following results were reported on each demonstration.

- Perimeter security and urban scenarios, Creech Air Force Base, Nevada, August 2005. Number of energy projections: 65. Personnel exposures: 914. Two personnel had a rash of small ankle blisters, no treatment required, healed in a few days.

- Urban scenarios, Fort Benning, Georgia, September 2005. Number of energy projections: 979. Personnel exposures: 1,462. One shin blister, no treatment required, healed in a few days.
- Maritime scenario, Eglin Air Force Base, Florida, April 2006**.** Number of energy projections: 305. Personnel exposures: 474. One small gum blister (needed magnification to see), no treatment required, healed in 24 hours.

Injury at Moody Air Force Base, Georgia

On April 4, 2007, a volunteer airman experienced second degree burns[13] (blister injures) on his legs, affecting about eight percent of his body area, as a result of an overexposure from System 1. The 23rd Wing, US Air Force conducted a safety investigation of the incident. At the time of the incident, the ADS was undergoing an extended evaluation by the 820th Security Forces Group at Moody Air Force Base. Specifically, the unit was training with the ADS and evaluating it in field scenarios.

The safety investigation concluded that incorrect power and duration settings were used for the range at which System 1 was operating in the scenario when the injury occurred. The injured airman was at or near the Fresnel maximum, where the power density is at its peak. System 1 can be operated safely at the Fresnel maximum, however the power and duration settings must be reduced.

The injured airman was taken to a local medical facility, and then sent to a burn treatment center in Augusta better equipped to treat his blister injuries. The center used their standard treatment proto-

[13] Second-degree burns involve the entire superficial layer of the skin and varying degrees of the secondary layer (dermis) of the skin and are often red, wet, and painful. Their depth, ability to heal, and propensity to form scars vary greatly. These burns are often accompanied by blisters, which develop immediately or within a few hours.

cols, which included debridement[14] of the burned areas and the use of pigskin grafts[15] as temporary bandages to promote healing. The burn treatment center released him after two days. The military placed him on convalescent leave for 30 days; however, he voluntarily returned to duty within two weeks. His injuries have healed without complications; however some reddening of the skin remains.

ADS subject matter experts supported the safety investigation of the incident. They duplicated the exposure of the individual, collecting target board data, and determined that the resulting blister injury was predictable at the power and duration settings used. The injury was due to thermal effects and not to any unknown or exotic effects.

Investigators determined that procedural requirements established in training and safety plans for the Active Denial System were not properly followed. As a result, several recommendations from the investigation are being implemented, and include increased training emphasis in several areas, better defined procedures, and software enhancements.

The ADS subject matter experts that supported the investigation of the incident briefed the HEAP. The HEAP agreed that this injury was predictable by scientific research and understood by researchers. The HEAP concurred as well that training, procedural, and software improvements were adequate for System 1, and that

[14] Debridement is the removal of dead, damaged, or infected tissue to improve the healing potential of the remaining healthy tissue.

[15] Pigskin grafts are used for more superficial second-degree burns (partial thickness burns) that will heal on their own if kept clean. The skin at the site will heal but the process can be made less troublesome by covering the area with a biologic dressing. Pigskin grafts are a temporary biologic dressing (bandage) that keeps the wound clean, reduces pain, and eliminates the discomfort and inconvenience of changing a non-biologic dressing (gauze etc) twice a day or more. The pigskin dries out and falls off on its own.

the lessons learned should be applied to support engineering effectiveness and safety in subsequent systems.

Section 3 Conclusion

The field and laboratory research have enabled a comprehensive understanding of the ADS bioeffects. This research effort has guided the development and fielding of the ADS. The challenge ahead is to ensure that this scientific understanding is transitioned to future operators so that the technology can continue to be used safely and effectively.

Conclusion

The Air Force Research Laboratory is commended for its bioeffects research. The subject of this research – millimeter wave energy – is commonly found in our present environment. This energy is used in communications and weather systems, and the technology to produce it has been around for about 50 years. What is new is AFRL's innovative use of millimeter waves. They discovered how this common energy and old technology can be used as a non-lethal weapon, one with a low probability of injury and a high probability of effectiveness.

Researchers… have found a wide safety margin between the desired repel response and injuries.

This millimeter wave energy's primary interaction is in the top 1/64th of an inch of the skin and cornea, and its principal effect is thermal. Researchers have comprehensively examined these thermal effects in several climes and locals. They have also determined when this energy causes thermal injuries, and found a wide safety margin between the desired repel response and injuries. Additionally, they have assessed the variables that could impact safety and effectiveness.

The ADS has been designed to save lives. It is no longer in the lab, nor is it reportedly with the warfighters who seek it. The greatest challenge may be public acceptability, particularly with those who don't understand millimeter waves and who believe it has exotic effects. AFRL's research has provided an excellent understanding of this energy's bioeffects. Now it is a matter of communicating this understanding to the public.

The HEAP continues to be impressed with the thoroughness of AFRL's research. AFRL's receptiveness to outside scrutiny, criticisms and recommendations is a reflection of its professionalism and conscientiousness. As one HEAP member stated, "Other research endeavors should be so thorough." The Panel holds this bioeffects research as a standard for non-lethal weapons development.